



GRASAS Y ACEITES 67 (2)

April–June 2016, e135

ISSN-L: 0017-3495

doi:<http://dx.doi.org/10.3989/gya.0622152>

Amazonian Buriti oil: chemical characterization and antioxidant potential

P. Speranza^{a,b,✉}, A. de Oliveira Falcão^b, J. Alves Macedo^b, L.H.M. da Silva^c,
A.M. da C. Rodrigues^c and G. Alves Macedo^{a,b,✉}

^aFaculty of Food Engineering, Department of Food Science, University of Campinas, 80,
Monteiro Lobato St., 13083-970, Campinas, SP, Brazil

^bFaculty of Food Engineering, Department of Food and Nutrition, University of Campinas

^cFaculty of Food Engineering, Technology Institute, University of Para

✉Corresponding authors: paulasperanza09@gmail.com; gmacedo@fea.unicamp.br

Submitted: 04 June 2015; Accepted: 22 December 2015

SUMMARY: Buriti oil is an example of an Amazonian palm oil of economic importance. The local population uses this oil for the prevention and treatment of different diseases; however, there are few studies in the literature that evaluate its properties. In this study, detailed chemical and antioxidant properties of Buriti oil were determined. The predominant fatty acid was oleic acid (65.6%) and the main triacylglycerol classes were tri-unsaturated (50.0%) and di-unsaturated-mono-saturated (39.3%) triacylglycerols. The positional distribution of the classes of fatty acids on the triacylglycerol backbone indicated a saturated and unsaturated fatty acid relationship similar in the three-triacylglycerol positions. All tocopherol isomers were present, with a total content of 2364.1 mg·kg⁻¹. α -tocopherol constitutes 48% of the total tocopherol content, followed by γ -tocopherol (45%). Total phenolic (107.0 mg gallic acid equivalent·g⁻¹ oil) and β -carotene (781.6 mg·kg⁻¹) were particularly high in this oil. The highest antioxidant activity against the free radical 1,1-diphenyl-2-picrylhydrazyl (DPPH) was obtained at an oil concentration of 50 mg·mL⁻¹ (73.15%). The antioxidant activity evaluated by the Oxygen Radical Absorbance Capacity (ORAC) was 95.3 μ mol Trolox equivalent·g⁻¹ oil. These results serve to present Buriti oil as an Amazonian resource for cosmetic, food and pharmaceuticals purposes.

KEYWORDS: Fatty acid; Minor compound; Radical scavenging activity; Regio-specific distribution; Triacylglycerol

RESUMEN: *Aceite de buriti de la Amazonia: Caracterización química y potencial antioxidante.* El aceite de Buriti es un ejemplo de aceite de palma amazónica de gran importancia económica. La población local utiliza este aceite para la prevención y el tratamiento de diferentes enfermedades; sin embargo, hay pocos estudios científicos que evalúen sus propiedades. En este estudio, se determinaron las propiedades antioxidantes del aceite de Buriti. El ácido graso predominante fue el oleico (65,6 %) y las principales clases de triglicéridos fueron tri-insaturadas (50,0 %) y Di-insaturados-mono-saturada (39,3 %). La distribución posicional de las clases de ácidos grasos en el esqueleto de triacilglicerol indicó una relación de ácidos grasos saturados e insaturados similar en las tres posiciones del triacilglicerol. Todas las isoformas de tocoferol estaban presentes, con un contenido total de 2364.1 mg·kg⁻¹. El α -tocoferol constituye el 48 % del contenido total de tocoferol, seguido de γ -tocoferol (45 %). El contenido fenólico total (107,0 mg equivalente ácido gálico·g⁻¹ de aceite) y β -caroteno (781,6 mg·kg⁻¹) fueron particularmente altos en este aceite. La mayor actividad antioxidante contra el radical 1,1-difenil-2-picrilhidrazil libre (DPPH) se obtuvo a una concentración de aceite de 50 mg·mL⁻¹ (73,15 %). La actividad antioxidante evaluadas por la capacidad de absorción de radicales de oxígeno (ORAC) fue 95,3 mmol Trolox equivalente·g⁻¹ de aceite. Estos resultados presentan al aceite de Buriti amazónico como buen recurso con fines cosmético, alimenticio y farmacéutico.

PALABRAS CLAVE: *Ácido graso; Actividad de captación de radicales; Componentes menores; Distribución regioespecífica; Triglicéridos*

Citation/Cómo citar este artículo: Speranza P, de Oliveira Falcão A, Alves Macedo J, da Silva LHM, da C. Rodrigues AM, Alves Macedo G. 2016. Amazonian Buriti oil: chemical characterization and antioxidant potential. *Grasas Aceites* 67 (2): e135. doi: <http://dx.doi.org/10.3989/gya.0622152>.

Copyright: © 2016 CSIC. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial (by-nc) Spain 3.0 Licence.

1. INTRODUCTION

Non-conventional vegetable oils have gained a pronounced importance because their constituents have unique chemical properties. Some of these vegetable oils may augment the supply of nutritional and functional products; others have importance in cosmetic and pharmaceutical applications (Ramandan *et al.*, 2009).

In Brazil, and specifically in its Amazonian area, a great variety of non-conventional plant oils, with many physicochemical and biological properties can be found (Bataglion *et al.*, 2014; Pesce *et al.*, 2009). A variety of seed oils, from different species, is commercialized in local markets with a variety of alleged proprieties (Saraiva *et al.*, 2009). Buriti (*Mauritia flexuosa* Mart) mesocarp oil is an example of an Amazonian palm oil of economic importance. This oil is used by the local population as healing, sunscreen, for the treatment of burns, for the prevention of skin aging, and acts as anti-inflammatory and antibiotic (Hernández *et al.*, 2009; Silva *et al.*, 2009; Rodrigues *et al.*, 2010). The Buriti oil has some features similar to palm oil such as its reddish-yellow color and its flavor (Pesce *et al.*, 2009).

However, while this oil presents a great potential for application either alone or in combination with other oils, most studies only present data on the fatty acid composition, oxidative stability and minor components such as carotenes and tocopherols (Pardauil *et al.*, 2011; Silva *et al.*, 2011; Silva *et al.*, 2009; Albuquerque *et al.*, 2005; Santos *et al.*, 2013a). The specialized literature does not present a more detailed assessment of its physical and chemical characteristics, and parameters such as regio-specific distribution are not reported.

In addition, biological studies with Buriti oil are scarce, basically relating to assessments of sunscreen and cytotoxic potential studies (Zanatta *et al.*, 2010; Zanatta *et al.*, 2008). Studies on the antioxidant activity with this oil are also scarce, with results restricted to a single radical (Ferreira *et al.*, 2011; Bataglion *et al.*, 2015). Furthermore, these studies generally evaluate the antioxidant activity of the oil after fractionation by difference in polarity and not the intact oil, which may adversely affect the results obtained (Espín *et al.*, 2000). Research on antioxidant activity has shown that products with antioxidant features are related to reducing risk of many diseases in which

oxidative stress may play a role, especially chronic illnesses such as cancer, cardiovascular, inflammatory and neuro-degenerative diseases (Pandey and Rizvi, 2009).

Therefore, the objective of this investigation is to obtain an information profile about the chemical nature and antioxidant potential against radicals 1,1-diphenyl-2-picrylhydrazyl (DPPH) and the Oxygen Radical Absorbance Capacity (ORAC) of Buriti mesocarp oil. The results are important to verify the cosmetic and nutraceutical potential of the Buriti oil. No previous studies in the literature have analyzed Buriti oil to this extent.

2. MATERIALS AND METHODS

Crude Buriti oil was bought in a local market in the city of Belém, State of Pará, in the Brazilian Amazon. All other reagents and solvents were of analytical grade.

2.1. Fatty acid composition

Fatty acid methyl esters were prepared according to the Hartman and Lago's method (Hartman and Lago, 1973). The fatty acid composition was determined as previously reported (Basso *et al.*, 2012).

2.2. Regio-specific distribution

Proton-decoupled ^{13}C NMR (Nuclear Magnetic Resonance) was used to analyze the positional distribution of the classes of fatty acids on the triacylglycerol (TAG) backbone. The determination of ^{13}C was performed at a frequency of 75.8 MHz, with a 5 mm multinuclear probe operating at 30 °C (Vlahov, 1998).

2.3. Triacylglycerol composition

The fatty acid composition was used to predict the groups of TAGs in the non-interesterified blend with PrÓleos software (Antoniosi Filho *et al.*, 1995). The composition of TAGs present in interesterified lipids was analyzed according to the 1,3-random, 2-random theory (non-random redistribution), and 1,2,3-random theory (random redistribution), based on the analysis of the regio-specific distribution described in item 3.4 (D'Agostini and Gioielli, 2002; Guedes *et al.*, 2014).

2.4. Minor compounds

Tocopherols

The α , β , γ , and δ -tocopherol contents were determined by High Performance Liquid Chromatography (HPLC), according to the Ce8–89 AOCS method (AOCS, 2009). Peaks were identified by comparison of their retention times with authentic standards of tocopherols and were quantified based on the peak areas relative to standard calibration plots by the external standard method.

Total carotenoid

The β -carotene content was obtained using the method described by Davies (1973). The oil was diluted in hexane at a concentration of $0.004 \text{ g} \cdot \text{mL}^{-1}$ and read at 446 nm using a computerized Shimadzu Spectrophotometer (Kyoto, Japan).

Total polyphenols

Phenolic compounds were extracted with water-methanol 60:40 (v/v). Folin-Ciocalteu reagent (Sigma Chemicals) was added to suitable aliquots of the methanolic extracts. After 3 minutes, a sodium carbonate solution (35%, w/v) was added to the reaction mixture, which was finally mixed and diluted with water to a final volume of $1000 \mu\text{L}$. The absorbance of the solution was measured after 2 h, against a blank sample produced with distilled water, on a Shimadzu Spectrophotometer (Kyoto, Japan) at a wavelength of 725 nm. Results are given as $\mu\text{g mL}^{-1}$ of gallic acid (Hrncirik and Fritsche, 2004).

2.5. Antioxidant assays

DPPH

The DPPH procedure was done according to Vorarat et al. (2010). The oil is dissolved in ethyl acetate at concentrations of 5, 10, 50 and $100 \text{ mg} \cdot \text{mL}^{-1}$. The reaction mixtures were mixed on 96-well plates (BMG Labtech 96) and the reaction was carried out on a NovoStar Microplate reader (BMG LABTECH, Germany) with absorbance filters for an excitation wavelength of 520 nm after 16 minutes. Results are presented as a function of absorbance (Free radical scavenging activity).

ORAC

The ORAC procedure was carried out according to the method of Prior et al. (2003) with some modification. The assay was carried out on a NovoStar Microplate reader with fluorescence filters for an excitation wavelength of 485 nm and an emission

wavelength of 520 nm at 37°C . The oil (40 mg) was diluted to a final volume of 1 mL of a mixture of dimethyl sulfoxide (DMSO): Triton X-20 (9:1) and stirred for 90 seconds on the ultra turrax (IKA-ULTRA-TURRAX®) for 5 min at 4000 rpm. For the analysis, $40 \mu\text{L}$ of this solution was added to the 96 well dark microplate. $400 \mu\text{L}$ of fluorescein in solution (70 nM) were added by injectors in the microplate reader, followed by $150 \mu\text{L}$ of AAPH ($17.2 \text{ mg} \cdot \text{mL}^{-1}$, $9.4 \mu\text{mol/well}$). Results are expressed in terms of trolox equivalents (TE).

2.6. Statistical Analysis

Results were presented as the mean \pm standard deviation from three replicates of each experiment. A p -value < 0.05 was used to denote significant differences among mean values determined by the analysis of variance (ANOVA) with the assistance of Statistica 7.0 (StatSoft, Inc., Tulsa, OK) software.

3. RESULTS AND DISCUSSION

3.1. Fatty acid compositions

The results in Table 1 indicate that Buriti oil is very rich in oleic acid (65.6%). The fatty acid composition also indicates that this oil presents palmitic acid as the major saturated fatty acid (19.2%). Regarding polyunsaturated fatty acids, the concentration in this oil does not exceed 13.3%.

The previous studies which address the fatty acid composition of Buriti oil confirm that oleic acid is the major fatty acid, followed by palmitic acid. Santos *et al.* (2013b), using the same technique to determine the fatty acids employed in this study (GC-FID), obtained similar values for oleic (71.6) and palmitic (20.8) acids; however, the values obtained for the polyunsaturated

TABLE 1. Fatty acid composition of Buriti oil

Fatty acids	Buriti (%)
Caprylic acid (C8:0)	–
Capric acid (C10:0)	–
Lauric acid (C12:0)	–
Myristic acid (C14:0)	0.5 ± 0.00
Palmitic acid (C16:0)	19.2 ± 0.03
Stearic acid (C18:0)	1.3 ± 0.00
Oleic acid (C18:1)	65.6 ± 0.0
Linoleic acid (C18:2)	4.9 ± 0.05
Linolenic acid (C18:3)	8.2 ± 0.01
Σ Saturated	21.0
Σ Monounsaturated	65.6
Σ Polyunsaturated	13.2

linoleic and linolenic acids were lower, at 2.5% and 1.4%, respectively. The same difference was observed in the study of Pardaul *et al.* (2011). Amounts of polyunsaturated fatty acids similar to ours were obtained in the study of Silva *et al.* (2009). Their methods of determination based on mass spectrometry (MS) also confirm that oleic (71%) and palmitic acids (20%) are the major fatty acids in Buriti oil, and stearic acid, as well as in our study, was also detected (Bataglioni *et al.*, 2015). This small variation in results is predictable and may be influenced by many factors, such as season, extraction and refining processes (Aquino *et al.*, 2012).

The fatty acid profile of Buriti oil reveals the lipid as a good source of monounsaturated fatty acids. A great interest has been placed in oils that contain these fatty acids. The high oleic and low linoleic fatty acid contents help make them more resistant to oxidation than most liquid oils (Santos *et al.*, 2013a; Silva *et al.*, 2009; O'Brien, 2009). Olive oil is a very flavor-stable oil because of the high oleic fatty acid content (70–80%) (O'Brien 2009; Criado *et al.*, 2008). Moreover, interest in oleic acid as a health-promoting nutrient has expanded in recent years (Capurso *et al.*, 2014; Sales-Campos *et al.*, 2013). Studies using animal cells have shown that oleic acid enhanced intra-cellular levels of lipid peroxidation, indicating that the acid can promote good adaptive response and increase the tolerance of the cells by increasing antioxidant capacity (Haeiwa *et al.*, 2014). Thus, the Buriti oil can represent a new option of oil rich in oleic acid, and thus, an alternative to olive oil.

3.2. Regio-specific distribution

The fatty acid distribution in TAG affects the physical properties, lipolytic and oxidative stability, and nutritional availability of lipids (Kolakowska and Sikorski, 2002). Buriti oil is characterized by a random distribution of oleic and saturated fatty acids in all glycerol positions. Polyunsaturated fatty acids are located almost exclusively in the sn-2 position (Figures 1 and 2).

The high proportion of oleic acid in all glycerol positions along with the predominance of polyunsaturated fatty acids in the sn-2 position make Buriti oil less susceptible to oxidation. In addition, the high concentration of saturated fatty acids in the sn-2 position of the Buriti oil provides a differentiated regio-specific distribution. In vegetable oils, unsaturated fatty acids tend to be located at the sn-2 position of the glycerol, while the saturated ones tend to be located at the sn-1 and sn-3 positions (Brockerhoff, 1971). In some applications, such as human milk fat substitute production, the aim is to enhance vegetable oils with unsaturated fatty acids at the sn-2 position, using lipases (Pina-Rodrigues

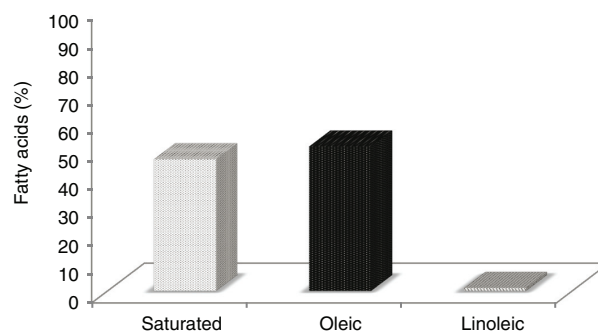


FIGURE 1. Regio-specific distribution of fatty acids at the sn-1,3 positions of Buriti oil.

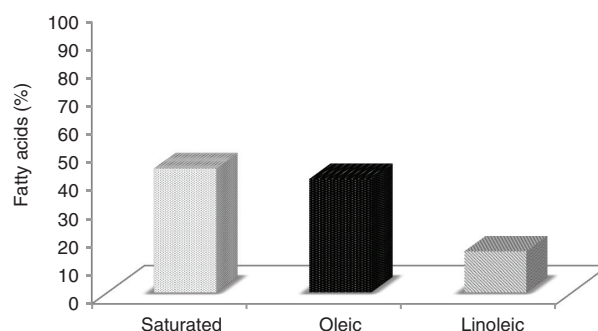


FIGURE 2. Regio-specific distribution of fatty acids at the sn-2 position of Buriti oil.

and Akoh, 2010). Buriti oil, to present this distribution of fatty acids naturally can be used for producing such fats.

The information about the stereo-specific positional distribution of fatty acids in the Buriti oil can be used for the development of the structural lipids for food, pharmaceutical and medical purposes.

3.3. Triacylglycerol composition

Triacylglycerol (TAG) composition is key to understanding the various physical properties of an oil or fat (Buchgraber *et al.*, 2004). Given the high contents in oleic (65.6%) and palmitic (19.2%) acids, which are the two major fatty acids in Buriti oil, TAG species combining both acids (i.e. oleic-oleic-oleic (OOO) and palmitic-oleic-oleic (POO)), were the major species in the oil analyzed. These two species account for over 50% of the TAGs presented in the oil (Table 2). Oleic-oleic-linolenic (OOLn) and palmitic-oleic-palmitic (POP) TAGs were also present in a significant percentage in Buriti oil (11.1 and 7.4, respectively). The results of this study are in agreement with other studies with

TABLE 2. Classes of TAG in Buriti oil

TAG	%
PPO	7.4
MOO	1.2
PPLn	1.0
POO	25.1
POL	3.9
POLn	6.4
SOO	1.6
OOO	28.8
OOL	6.9
OOLn	11.1
OLLn	1.6
OLnLn	1.4
Others	3.6
Sum	100.0
Total SSS	0.9
Total SUS	9.8
Total SUU	39.3
Total UUU	50.0

L: linoleic acid; Ln: linolenic acid;
M: myristic acid; O: oleic acid;
P: palmitic acid; S: stearic acid.

Buriti oil. Santos *et al.* (2013b) and Saraiva *et al.* (2009) found OOO (39.8% and 35.6%, respectively) and POO (35.9% and 34.5%, respectively), as dominant species, although in the study of Saraiva *et al.* (2009) a higher concentration of palmitic-oleic-stearic was obtained (POS, 7.8%) and oleic-oleic-stearic (OOS, 10.7%) TAGs and in the study of Santos *et al.* (2009) were not detected oleic-oleic-linoleic (OOL) TAG specie. These small differences in the TAG species are related to the variation in the concentration of fatty acids (Table 1).

The tri-unsaturated TAGs (U_3), prevalent in Buriti oil, with melting points from -14 to 1 °C, are important for the softness and lubricity of some products at room temperature, and offer the nutritional benefits of unsaturated fatty acids. The mono-saturated-di-unsaturated (SU_2) TAGs, with melting points from 1 to 23 °C are important for the oral properties and mechanical-performance of some products at room temperature (O'Brien, 2009; Rodrigues and Gioielli 2003; Bessler and Orthoefer 1983).

The TAG composition of Buriti oil is similar to olive oil, which presents the TAG OOO (32.5%), followed by POO (21.82%), as the main species of TAGs (Criado *et al.*, 2008). Both oils have TAG SU_2 between 50 and 60%, and TAG U_3 between 38–40% (O'Brien, 2009).

The information about the stereo-specific positional distribution of fatty acids in camellia oil can

be used for the development of structured lipids for food, pharmaceutical, and medical purposes.

3.4. Minor compounds

Tocopherols

Tocopherols are natural antioxidants present in fats and oils. The antioxidant activity is due not only to the de-activation of free radicals produced by the decomposition of lipid hydroperoxides, but also to the inhibition of lipid hydroperoxide decomposition (Pokorny and Parkányiová, 2005; Makinen *et al.*, 2001). In addition, previous studies have shown that tocopherols have substantial health benefits such as hypocholesteremic, hypolipidemic, anticancer, anti-inflammatory and antioxidant properties and slow down the aging process (Ghaffari *et al.*, 2011; Singh and Devaraj 2007; Hau *et al.*, 2006).

The data obtained on the qualitative and quantitative composition of tocopherols in Buriti oil are summarized in Table 3. This oil is particularly rich in tocopherols ($2364.1 \text{ mg}\cdot\text{kg}^{-1}$) and such high values are encountered in a very limited number of oils (Tuberoso *et al.*, 2007). Vegetable oils normally contain tocopherol concentrations in the range of 200 – $1000 \text{ mg}\cdot\text{kg}^{-1}$ (Chen *et al.*, 2011).

All tocopherols were present in Buriti oil, wherein α - and γ - constituted 93% of the total tocopherol content. The α -tocopherol shows the highest vitamin E activity and is the most effective antioxidant *in vivo* compared to other isomers (Ghazani and Marangini, 2013). γ -tocopherol has a complementary effect to the α -tocopherol in relation to human health (Wagner *et al.*, 2004). These results are similar to those found by Santos *et al.* (2013a) and Rodrigues *et al.* (2010) where Buriti oil presents α -tocopherol as the most important homologue.

Total carotenoid

The search for natural sources of β -carotene is of great interest, since only 2% of all commercial β -carotene is naturally produced worldwide (Dufossé *et al.*, 2005; Ribeiro *et al.*, 2011). Carotenoids attracted attention because a number of epidemiological studies have revealed that an

TABLE 3. Minor compounds in Buriti oil

Compounds	$\text{mg}\cdot\text{kg}^{-1}$
α -tocopherols	1125.0 ± 3.9
β -tocopherols	71.3 ± 0.0
γ -tocopherols	1074.0 ± 3.4
δ -tocopherols	93.8 ± 0.5
Total β -carotene	781.6 ± 67.3
Total phenol (gallic acid equivalent)	107.0 ± 1.2

increased consumption of a diet rich in carotenoids is correlated with a diminished risk for several degenerative disorders, including various types of cancer, cardiovascular or ophthalmological diseases (Stahl and Sies, 2003; Mayne, 1996). The preventive effects have been associated with their antioxidant activity, protecting cells and tissues from oxidative damage (Sies and Stahl, 1995). Carotenoids also influence cellular signaling and may trigger redox-sensitive regulatory pathways (Stahl *et al.*, 2002). The bioactivity of these compounds depends on the foods matrix where they are present. β -carotene which is present in oils has a bioactivity six times higher than that found in vegetables (Benadé, 2013).

Data about the carotenoid composition in Buriti oil are presented in Table 3. The results indicate that this oil is one of the richest known sources of biological active β -carotene ($781.6 \text{ mg}\cdot\text{kg}^{-1}$), which imparts the characteristic orange-red color and also lends oxidative protection to the oil (Ribeiro *et al.*, 2011; Benadé, 2013). In the literature, the total carotenoid content of Buriti oil fluctuates between $600 \text{ mg}\cdot\text{kg}^{-1}$ to $10,000 \text{ mg}\cdot\text{kg}^{-1}$, probably depending on the varietal selection, the degree of ripeness, agronomical factors, and extraction procedure (Santos *et al.*, 2015).

In a study that assess the antioxidant activity of carotenoids measured by ferric reducing antioxidant power (FRAP), ABTS bleaching assay (α -TEAC), DPPH assay and peroxy radical scavenging assay compared to α -tocopherol, BHA and BHT, most of them showed carotenoid as the greatest antioxidant. The carotenoid tested displayed an antioxidant activity more than eight times as high as α -tocopherol (Muller *et al.*, 2011). Due to the ability of the carotenoids to quench singlet oxygen, such as the superoxide radical, peroxide radical and hydroxyl radical, which can be generated by exposure to UV radiation, studies using Buriti oil in sunscreen formulations are promising (Zanatta *et al.*, 2010). In another study, red palm oil, which is rich in carotenoids such as Buriti oil (between 500 and $700 \text{ mg}\cdot\text{kg}^{-1}$ total carotenoids), has been used to combat vitamin A deficiency in Africa (Benadé, 2013; Gunstone and Harwood, 2007).

Total polyphenol

Phenolic compounds have significant biological potential, especially in preventing oxidative stress, inflammation and bacterial infection (Lesjak *et al.*, 2014). In addition these effects on health, such phenolic compounds, due to their antiradical activity, can protect the tocopherols present in the oil and prevent the autoxidation of unsaturated fatty acids, increasing the shelf-life of the oil (Valavanidis *et al.*, 2004).

The results in Table 3 show that the Buriti oil is a source of phenolic compounds (107.0 mg gallic

acid equivalents $\cdot\text{kg}^{-1}$). Although the concentration of this compound in this oil is not as high as olive oil ($170\text{--}210 \text{ mg}$ gallic acid equivalents $\cdot\text{kg}^{-1}$), it is superior to many other vegetable oils (Tuberoso *et al.*, 2007). Non-traditional oils, such as black cumin oil, coriander seed oil and niger seed oil, sources of bioactive compounds with antioxidant potential, present phenolic compound concentrations of 24, 11 and $5 \text{ mg}\cdot\text{kg}^{-1}$, respectively, which are lower than the one found in Buriti oil, which reinforces the great nutritional and health potential of this oil (Ramadan *et al.*, 2003).

3.5 Antioxidant assay

DPPH

The assays which determine the antioxidant potency of oils can be categorized into two groups: tests for radical scavenging ability and tests that examine the ability to inhibit lipid oxidation. However, the model for scavenging stable free radicals is widely used to estimate the antioxidant properties in a relatively short time and with reliability (Reische *et al.*, 2002; Ramadan and Moersel 2006).

Table 4 shows the antioxidant capacity of Buriti oil expressed as percentage of decrease in the absorbance (Free radical scavenging activity). As a result of a color change from purple to yellow the absorbance decreased when the DPPH radical was scavenged by an antioxidant through donation of hydrogen to form a stable DPPH-H molecule (Matthaus, 2002). Thus, a higher percentage of absorbance decrease indicates a greater free radical scavenger.

The oil was dissolved in ethyl acetate in different concentrations ($5\text{--}100 \text{ mg}\cdot\text{mL}^{-1}$) against the free radical DPPH. The results demonstrate that a dose-dependent effect, in general, was noted; the higher the oil dose, the stronger the radical scavenging ability obtained. However, at the concentration of $50 \text{ mg}\cdot\text{mL}^{-1}$ of oil, free radical scavenging activity begins to be stabilized; doubling the oil concentration increases the free radical scavenging by only 6%.

The choice of ethyl acetate as solvent was due to its ability to dissolve the oil without the need to fractionate it. A previous study suggests that the

TABLE 4. Antioxidant capacity of Buriti oil by DPPH assay.

Oil concentration ($\text{mg}\cdot\text{mL}^{-1}$)	Free radical scavenging activity
5	36.53 ± 1.35^a
10	39.74 ± 1.58^{ab}
50	73.15 ± 1.4^a
100	78.07 ± 2.13^{ab}

^{a,ab} - Means with the same letter in the column are not significantly different at the 5% significance level.

assessment of antioxidant potential without the polar and non-polar fractions of the oil demonstrate a higher antioxidant potential. This could be due to the synergistic effect of the different antioxidants present in both the non-polar and polar fractions (Espín *et al.*, 2000).

Comparison of the results obtained in this study with other studies is inaccurate, since experimental conditions differ. Different solvents may cause differences in the antioxidant pattern between the groups' assays, since it has been shown that the solvent may affect the hydrogen-donating ability of the antioxidant (Ramadan and Moersel, 2006). However, the results of this study, compared to other oils with antioxidant activity, suggest that the Buriti oil proved to be efficient in DPPH radical scavenging. In a study with olive oil, which has a fatty acid and TAG composition similar to Buriti oil, it is observed that olive oil reduced the free radical DPPH by 8.8% after 60 minutes of reaction (Ramadan and Moersel, 2006). In this same study, coriander seed oil was able to quench the free radical in 26.7% after 60 minutes of reaction. Coriander seed oil is rich in oleic acid (67%) and presents a carotenoid concentration of 892 mg·kg⁻¹; physicochemical characteristics which are similar to Buriti oil.

Some studies evaluate the results of DPPH in EC₅₀, defined as the concentration in mg·mL⁻¹ required to scavenge 50% of the DPPH free radical. In a study with Buriti oil, using chloroform as a solvent, it was found that the oil's antioxidant capacity is similar to other oils from the Amazonian area, with EC₅₀ 7.7 mg·mL⁻¹ (Ferreira *et al.*, 2011). The results, although impossible to compare with those obtained in this study, confirm the antioxidant potential of Buriti oil against the DPPH radical.

ORAC

The ORAC assay measures the oxidative degradation of the fluorescent molecule, namely fluorescein. In the presence of antioxidants, loss in fluorescence in the fluorescein is inhibited and this inhibition is directly related to antioxidant activity (Miraliakbari and Shahidi, 2008).

The ORAC value found for Buriti oil was 95.3 μmol TE·g⁻¹ oil, a value similar to other oils rich in minor compounds and known for positive health effects (Zullo and Ciafardini, 2008; Dhavamani *et al.*, 2014). Although, as with the DPPH analysis, comparison of the results of this study with other studies it is inaccurate, and serves only as a reference. No other study assessing the antioxidant activity of Buriti oil without its fractionation was found, but a study that evaluated the ORAC value of the lipophilic and hydrophilic fractions of this oil indicated that the hydrophilic fraction (8.3 μmol TE·g⁻¹ oil), due to synergistic effects of the pool of antioxidants, presents a value almost 5 times

higher than the lipophilic fraction (1.8 μmol TE·g⁻¹ oil) (Bataglion *et al.*, 2015). When comparing these results with those obtained in our study, the big difference in the total ORAC (95.3 and 10.1 μmol TE·g⁻¹ oil, respectively) is, as mentioned above, due to the synergistic effect of the different antioxidants present in both non-polar and polar fractions, type of solvent used or even oil characteristics. When comparing the results with various integral olive oils from Italy, known for high antioxidant potential, the total ORAC value found was between 146–280 μmol TE·g⁻¹ oil, relatively close to those obtained in our study (Zullo and Ciafardini, 2008). In another study that evaluated the antioxidant activity of various oils rich in minor compounds, rice bran oil presented an ORAC content of 130.0 μg TE·mg⁻¹, sesame oil 122 μg TE·mg⁻¹, olive oil 111 μg TE·mg⁻¹ and palm oil 79 μg TE·mg⁻¹ (Dhavamani *et al.*, 2014). These results indicate that Buriti oil, as well as with the DPPH assay, is a good antioxidant in the ORAC assay.

The antioxidant activity of bioactive compounds is related to the preservation of chain initiation by binding oxygen or catalytic metal ions to delay the oxidation, decomposition of peroxides, prevention of continued hydrogen abstraction and radical scavenging protecting against oxidative damage to DNA, proteins and lipids (Marineli *et al.*, 2014; Halliwell, 1994). The use of Buriti oil in cosmetic formulations, food and pharmaceuticals could be interesting for health improvement. This result reinforces the importance to comprehensively evaluate the chemical composition and antioxidant properties of unexplored Amazonian oils.

5. CONCLUSIONS

Amazonian vegetable oils have attracted attention because of their often-remarkable biological properties. Many oils are known to possess biological properties and have been used by the local population to treat many diseases. Enlarging the scientific data on the chemical, technological and biological properties of the Amazon Buriti oil can facilitate the development of industrial applications for this non-conventional oilseed.

ACKNOWLEDGMENTS

The authors are grateful to Renato Grimaldi and Ana Paula Badan Ribeiro (DTA/LOG-Unicamp) for their support during the analyses. The authors are also grateful to Dr. Rodrigo Corrêa Basso (DEA-Unicamp) for his support during the fatty acid analyses. Financial supports were provided by The National Council for the Improvement of Higher Education (Capes) and by grant # 2012-22774-5 and grant # 2012-22829-4, São Paulo Research Foundation (Fapesp).

REFERENCES

- Albuquerque MLS, Guedes I, Alcantara Jr. P, Moreira SGC, Barbosa Neto NM, Correa DS, Zilio SC. 2005. Characterization of Buriti (*Mauritia flexuosa* L.) Oil by Absorption and Emission Spectroscopies. *J. Braz. Chem. Soc.* **16**, 1113–1117.
- Antoniosi Filho NR, Mendes OL, Lanças FM. 1995. Computer prediction of triacylglycerol composition of vegetable oils by HRGC. *Chromatographia* **40**, 557–562.
- AOCS. 2009. Official Methods and Recommended Practices of the American Oil Chemists' Society. American Oil Society (6th ed.). Champaign.
- Aquino JS, Pessoa DCNP, Araújo KLG, Epaminondas PS, Schuler ARP, Souza AG. 2012. Stamford TLM. Refining of Buriti oil (*Mauritia flexuosa*) originated from the Brazilian cerrado: physicochemical, thermal-oxidative and nutritional implications. *J. Braz. Chem. Soc.* **23**, 212–219. <http://dx.doi.org/10.1590/S0103-50532012000200004>.
- Basso RC, Almeida AJ, Batista EAC. 2012. Liquid-liquid equilibrium of pseudoternary systems containing glycerol+ethanol+ethyl biodiesel from crambe oil (*Crambe abyssinica*) at T/K = (298.2, 318.2, 338.2) and thermodynamic modeling. *Fluid Phase Equilib.* **333**, 55–62. <http://dx.doi.org/10.1016/j.fluid.2012.07.018>.
- Bataglion GA, Silva FMA, Santos JM, Santos FN, Barcia MT, Lourenço CC, Salvador MJ, Godoy HT, Eberlin MN, Koolen HHF. 2014. Comprehensive characterization of lipids from Amazonian vegetable oils by mass spectrometry techniques. *Food Res. Int.* **64**, 472–481. <http://dx.doi.org/10.1016/j.foodres.2014.07.011>.
- Bataglion GA, Silva FMA, Santos JM, Barcia MT, Godoy HT, Eberlin MN, Koolen HHF. 2015. Integrative approach using GC-MS and easy ambient sonic-spray ionization mass spectrometry (EASI-MS) for comprehensive lipid characterization of Buriti (*Mauritia flexuosa*) oil. *J. Braz. Chem. Soc.* **26**, 171–177. <http://dx.doi.org/10.5935/0103-5053.20140234>.
- Benadé AJS. 2013. Red palm oil carotenoids: Potential role in disease prevention, in Watson RR and Preedy VR (Eds.) *Bioactive Food as Dietary Interventions for Cardiovascular Disease*. Ed. Elsevier, 345–353.
- Bessler TR, Orthoefer FT. 1983. Providing lubricity in food fat systems. *J. Am. Oil Chem. Soc.* **60**, 1765–1768.
- Brockerhoff H. 1971. Stereospecific analysis of triglycerides. *Lipids*, 942–956.
- Buchgraber M, Ulberth F, Emons H, Anklan E. 2004. Triacylglycerol profiling by using chromatographic techniques. *Eur J Lipid Sci Technol* **106**, 621–648. <http://dx.doi.org/10.1002/ejlt.200400986>.
- Capurso C, Massaro M, Scoditti E, Vendemiale G, Capurso A. 2014. Vascular effects of the mediterranean diet Part I: Anti-hypertensive and anti-thrombotic effects. *Curr. Vasc. Pharmacol.* **118–126**. <http://dx.doi.org/10.1016/j.vph.2014.10.001>.
- Chen B, McClements DJ, Decker EA. 2011. Minor components in food oils: A critical review of their roles on lipid oxidation chemistry in bulk oils and emulsions. *Crit. Rev. Food Sci. Nutr.* **51**, 901–916. <http://dx.doi.org/10.1080/10408398.2011.606379>.
- Criado M, Hernández-Martín E, López-Hernández A, Otero C. 2008. Enzymatic interesterification of olive oil with fully hydrogenated palm oil: Characterization of fats. *Eur. J. Lipid Sci. Technol.* **110**, 714–724. <http://dx.doi.org/10.1002/ejlt.200800017>.
- D'Agostini, D, Gioielli LA. 2002. Stereospecific distribution of structured lipids obtained from palm oil, palm kernel oil, and medium chain triacylglycerols. *Rev. Bras. Cienc. Farm.* **38**, 345–354. <http://dx.doi.org/10.1590/S1516-93322002000300010>.
- Davies BH. 1976. Carotenoids, in Goodwin TW (Ed.) *Chemistry and biochemistry of plant pigments*. Academic, London, p.38.
- Dhavamani S, Rao YPC, Lokesh BR. 2014. Total antioxidant activity of selected vegetable oils and their influence on total antioxidant values in vivo: A photochemiluminescence based analysis. *Food Chem.* **164**, 551–555. <http://dx.doi.org/10.1016/j.foodchem.2014.05.064>.
- Dufosse L, Galaup P, Yaron A, Arad SM, Blanc P, Murthy KNC, Ravishankar GA. 2005. Microorganisms and microalgae as source of pigments for food use: a scientific oddity or an industrial reality? *Trends Food Sci. Tech.* **16**, 389–406. <http://dx.doi.org/10.1016/j.tifs.2005.02.006>.
- Espin JC, Soles-Rivas C, Wichers HJ. 2000. Characterization of the Total Free Radical Scavenger Capacity of Vegetable Oils and Oil Fractions Using 2,2-Diphenyl-1-picrylhydrazyl Radical. *J. Agric. Food Chem.* **48**, 648–656. <http://dx.doi.org/10.1021/jf9908188>.
- Ferreira BS, Almeida CG, Faza LP, Almeida A, Diniz CG, Silva VL, Grazul RM, Hyaric ML. 2011. Comparative Properties of Amazonian Oils Obtained by Different Extraction Methods. *Molecules*, **16**, 5875–5885. <http://dx.doi.org/10.3390/molecules16075875>.
- Ghaffari T, Nouri M, Irannejad E, Rashidi MR. 2011. Effect of vitamin E and selenium supplement on paraoxonase 1-activity, oxidized low density lipoprotein and antioxidant defense in diabetic rats. *BioImpacts* **1**, 121–128. <http://dx.doi.org/10.5681/bi.2011.016>.
- Ghazani SM, Marangoni AG. 2013. Minor Components in Canola Oil and Effects of Refining on These Constituents: A Review. *J. Am. Oil Chem. Soc.* **90**, 923–932. <http://dx.doi.org/10.1007/s11746-013-2254-8>.
- Guedes AMN, Ming CC, Ribeiro APB, Silva RC, Gioielli LA, Gonçalves LAG. 2014. Physicochemical Properties of Interesterified Blends of Fully Hydrogenated *Crambe abyssinica* Oil and Soybean Oil. *J. Am. Oil Chem. Soc.* **91**, 111–123. <http://dx.doi.org/10.1007/s11746-013-2360-7>.
- Gunstone FD, Harwood JL. 2007. Occurrence and characterization of oils and fats, in Gunstone FD, Harwood JL, Dijkstra AJ (Eds). *The lipid handbook*. 3rd edn. Taylor and Francis, pp. 703–782.
- Haeiwa H, Fujita T, Yasukazu SY, Miwa N. 2014. Oleic acid promotes adaptability against oxidative stress in 3T3-L1 cells through lipohormesis. *Mol. Cell Biochem.* **386**, 73–83. <http://dx.doi.org/10.1007/s11010-013-1846-9>.
- Halliwell B. 1994. Free radicals and antioxidants: a personal view. *Nutr. Res. Rev.* **52**, 253–265. <http://dx.doi.org/10.1111/j.1753-4887.2012.00476.x>.
- Hartman L, Lago RCA. 1973. Rapid preparation of fatty acid methyl esters from lipids. *Laboratory Practice* **22**, 475–494. <http://dx.doi.org/10.1021/ac60235a044>.
- Hau SN, Adolfsson O, Lee C-K, Ordozva J, Meydani SN. 2006. Age- and vitamin E-induced changes in gene expression profiles of T cells. *J. Immunol.* **177**, 6052–6061. <http://dx.doi.org/10.4049/jimmunol.177.9.6052>.
- Hernández PBN, Fregapane G, Moya MDS. 2009. Bioactive compounds, volatiles and antioxidant activity of virgin seje oils (*Jessenia Bataua*) from the Amazona. *J Food Lipids* **16**, 629–644. <http://dx.doi.org/10.1111/j.1745-4522.2009.01171.x>.
- Hrnčirik K, Fritsche S. 2004. Comparability and reliability of different techniques for the determination of phenolic compounds in virgin olive oil. *Eur. J. Lipid Sci. Technol.* **8**, 540–549. <http://dx.doi.org/10.1002/ejlt.200400942>.
- Kolakowska A, Sikorski ZE. 2002. The role of lipids in food quality. In: Kolakowska A, Sikorski ZE (ed). *Chemical and Functional Properties of Food Lipids*. CRC Press, Boca Raton, Florida.
- Lesjak MM, Beara IN, Orcic DZ, Petar KN, Simin ND, Emilija SD, Mäkinen MA, Kamal-Eldin A, Lampi A-M, Hopia A. 2001. α - β - γ - δ -Tocopherols as inhibitors of isomerization and decomposition of cis, trans methyl linoleate hydroperoxides. *Eur. J. Lipid Sci. Technol.* **103**, 286–291. <http://dx.doi.org/10.1021/jf0348525>.
- Mayne ST. 1996. Beta-carotene, carotenoids and disease prevention in humans. *Faseb J.* **10**, 690–701.
- Mäkinen MA, Kamal-Eldin A, Lampi A-M. 2001. Hopia A. α - β - γ - δ -Tocopherols as inhibitors of isomerization and decomposition of cis, trans methyl linoleate hydroperoxides. *Eur. J. Lipid Sci. Technol.* **103**, 286–291. <http://dx.doi.org/10.1021/jf0348525>.
- Marineli RS, Moraes EA, Lenquiste SA, Godoy AT, Eberlin MN, Maróstica Jr. MR. 2014. Chemical characterization

- and antioxidant potential of Chilean chia seeds and oil (*Salvia hispanica* L.). *LWT- Food Sci. Technol.* **59**, 1304–1310. <http://dx.doi.org/10.1016/j.lwt.2014.04.014>.
- Matthäus B. 2002. Antioxidant activity of extracts obtained from residues of different oilseeds. *J. Agr. Food Chem.* **50**, 3444–52. <http://dx.doi.org/10.1021/jf011440s>.
- Miraliakbari H, Shahidi F. 2008. Antioxidant activity of minor components of tree nut oils. *Food Chem.* **111**, 421–427. <http://dx.doi.org/10.1016/j.foodchem.2008.04.008>.
- Muller L, Frohlich K, Bohm V. 2011. Comparative antioxidant activities of carotenoids measured by ferric reducing antioxidant power (FRAP), ABTS bleaching assay (α TEAC), DPPH assay and peroxyl radical scavenging assay. *Food Chem.* **129**, 139–148. <http://dx.doi.org/10.1016/j.foodchem.2011.04.045>.
- O'Brien RD. 2009. *Fats and Oils: formulating and processing for applications*. 3rd edn. CRC Press, United States of America.
- Pandey KB, Rizvi SI. 2009. Plant polyphenols as dietary antioxidants in human health and disease. *Oxid Med Cell Longev.* **2**, 270–278. <http://dx.doi.org/10.4161/oxim.2.5.9498>.
- Pardaul JJR, Souza LKC, Molfetta FA, Zamian JR, Rocha Filho GN, Costa CEF. 2011. Determination of the oxidative stability by DSC of vegetable oils from the Amazonian area. *Bioresource Technol.* **102**, 5873–5877. <http://dx.doi.org/10.1016/j.biortech.2011.02.022>.
- Pesce C, Rocha ES, Filho NR, Zoghbi MGB. 2009. *Oleaginosas da Amazônia*. 2nd edn. Museu Paraense Emílio Goeldi, Brazil.
- Pina-Rodrigues AM, Akoh CC. 2010. Composition and oxidative stability of a structured lipid from Amaranth oil in a milk-based infant formula. *J. Food Sci.* **75**, 140–146. <http://dx.doi.org/10.1111/j.1750-3841.2009.01460.x>.
- Pokorny J, Parkányiová J. 2005. Lipids with antioxidant properties, in Akoh CC, Lai O-M (Ed). *Healthful Lipids*. AOCS Press, Champaign, Illinois, chapter 13.
- Prior RL, Hoang H, Gu L, Wu X, Bacchiocca M, Howard L, Hampsch-Woodill M, Huang D, Ou B, Jacob R. 2003. Assays for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity (ORAC (FL)) of plasma and other biological and food samples. *J. Agric. Food Chem.* **51**, 3273–9. <http://dx.doi.org/10.1021/jf0262256>.
- Ramadan MF, Kinni SG, Rajanna LN, Seetharam YN, Seshagiri M, Morsel J-T. 2009. Fatty acids, bioactive lipids and radical scavenging activity of *Celastrus paniculatus* Willd. seed oil. *J. Hortic.* **123**, 104–109. <http://dx.doi.org/10.1016/j.scienta.2009.07.008>.
- Ramadan MF, Kroh LW, Morsel JT. 2003. Radical scavenging activity of black cumin (*Nigella sativa* L.), coriander (*Coriandrum sativum* L.) and niger (*Guizotia abyssinica* Cass.) crude seed oils and oil fractions. *J. Agr. Food Chem.* **51**, 6961–6969. <http://dx.doi.org/10.1021/jf0346713>.
- Ramadan MF, Morsel JT. 2006. Screening of the antiradical action of vegetable oils. *J. Food Compos. Anal.* **19**, 838–842. <http://dx.doi.org/10.1016/j.jfca.2006.02.013>.
- Reische DW, Lillard DA, Eitenmiller RR. 2002. Antioxidants, in Akoh CC, Min DB (Eds). *Food Lipids*. Marcel Dekker, New York, pp. 423–448.
- Ribeiro BD, Barreto DW, Coelho MAZ. 2011. Technological aspects of β -carotene production. *Food Bioprocess Technol.* **4**, 693–701. <http://dx.doi.org/10.1007/s11947-011-0545-3>.
- Rodrigues JN, Gioielli LA. 2003. Chemical interesterification of milkfat and milkfat-corn oil blends. *Food Res. Int.* **36**, 149–159. [http://dx.doi.org/10.1016/S0963-9969\(02\)00130-8](http://dx.doi.org/10.1016/S0963-9969(02)00130-8).
- Rodrigues AMC, Darnet S, Silva LHM. 2010. Fatty acid profile and tocopherol contents of buriti (*Mauritia flexuosa*), patawa (*Oenocarpus bataua*), Tucuma (*Astrocaryum vulgare*), Mari (*Poroqueiba paraensis*) and Inaja (*Maximiliana maripa*) fruits. *J. Braz. Chem. Soc.* **21**, 2000–2004. <http://dx.doi.org/10.1590/S0103-50532010001000028>.
- Sales-Campos H, Souza PR, Peghini BC, Silva JS, Cardoso CR. 2013. An overview of the modulatory effects of oleic acid in health and disease. *Mini-Rev. Med. Chem.* **13**, 201–210. <http://dx.doi.org/10.2174/138955713804805193>.
- Santos MFG, Alves RE, Ruiz-Méndez MV. 2013a. Minor components in oils obtained from Amazonian palm fruits. *Grasas Aceites*, **64**, 531–536. <http://dx.doi.org/10.3989/gya.048913>.
- Santos MFG, Alves RE, Ruiz-Méndez MV. 2013b. Major components in oils obtained from Amazonian palm fruit. *Grasas Aceites*, **64**, 328–334. <http://dx.doi.org/10.3989/gya.023513>.
- Santos MFG, Alves RE, Roca M. 2015. Carotenoid composition in oils obtained from palm fruits from the Brazilian Amazon. *Grasas Aceites* **66**. <http://dx.doi.org/10.3989/gya.1062142>.
- Saraiva SA, Cabral EC, Eberlin MN, Catharino RR. 2009. Amazonian vegetable oils and fats: fats typification and quality control via triacylglycerol (TAG) profiles from dry matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry fingerprinting. *J. Agr. Food Chem.* **57**, 4030–4034. <http://dx.doi.org/10.1021/jf900043u>.
- Sies H, Stahl W. 1995. Vitamins E and C, beta-carotene, and other carotenoids as antioxidants. *Am. J. Clin. Nutr.* **62**, 1315S–1321S. [http://dx.doi.org/10.1016/S0083-6729\(07\)76020-X](http://dx.doi.org/10.1016/S0083-6729(07)76020-X).
- Silva SM, Sampaio KA, Taham T, Rocco SA, Ceriani R, Meirelles AJA. 2009. Characterization of Oil Extracted from Buriti Fruit (*Mauritia flexuosa*) Grown in the Brazilian Amazon Region. *J. Am. Oil Chem. Soc.* **86**, 611–616. <http://dx.doi.org/10.1007/s11746-009-1400-9>.
- Silva SM, Rocco SA, Sampaio KA, Taham T, Silva LHM, Ceriani R, Meirelles AJA. 2011. Validation of a method for simultaneous quantification of total carotenes and tocopherols in vegetable oils by HPLC. *Food Chem.* **129**, 1874–1881. <http://dx.doi.org/10.1016/j.foodchem.2011.05.137>.
- Singh U, Devaraj S. 2007. Vitamin E: inflammation and atherosclerosis. *Vitam. Horm.* **76**, 519–49. [http://dx.doi.org/10.1016/S0083-6729\(07\)76020-X](http://dx.doi.org/10.1016/S0083-6729(07)76020-X).
- Stahl W, Sies H. 2003. Antioxidant activity of carotenoids. *Mol. aspects Med.* **6**, 345–351. [http://dx.doi.org/10.1016/S0098-2997\(03\)00030-X](http://dx.doi.org/10.1016/S0098-2997(03)00030-X).
- Stahl W, Ale-Agha N, Polidori MC. 2002. Non-antioxidant properties of carotenoids. *Biol. Chem.* **383**, 553–558. <http://dx.doi.org/10.1515/BC.2002.056>.
- Tuberoso CIG, Kowalczyk A, Sarritzu E, Cabras P. 2007. Determination of antioxidants compounds and antioxidant activity in commercial oilseeds for food use. *Food Chem.* **103**, 1494–1501. <http://dx.doi.org/10.1016/j.foodchem.2006.08.014>.
- Valavanidis A, Nisiotou C, Papageorgiou Y, Kremli I, Satravelas N, Zinieris N, Zygali H. 2004. Comparison of the radical scavenging potential of polar and lipidic fractions of olive oil and other vegetable oils under normal conditions and after thermal treatment. *J. Agric. Food Chem.* **52**, 2358–2365. <http://dx.doi.org/10.1021/jf030491h>.
- Vlahov G. 1998. Regiospecific analysis of natural mixtures of triglycerides using quantitative ¹³C nuclear magnetic resonance of acyl chain carbonyl carbons. *Magn. Reson. Chem.* **36**, 359–362.
- Vorarat S, Managit C, Iamthanakul L, Soparat W, Kamkaen N. 2010. Examination of antioxidant activity and development of rice bran oil and gamma-oryzanol microemulsion. *J. Health Res.* **24**, 67–72.
- Wagner K-H, Kamal-Eldinb A, Elmadfa I. 2004. Gamma-Tocopherol-An underestimated vitamin? *Ann. Nutr. Metab.* **48**, 169–188. <http://dx.doi.org/10.1159/000079555>.
- Zanatta CF, Mitjans M, Ugartondo V, Rocha-Filho PA, Vinardell MP. 2010. Photoprotective potential of emulsions formulated with buriti oil (*Mauritia flexuosa*) against UV irradiation on keratinocytes and fibroblasts cell lines. *Food Chem. Toxicol.* **48**, 70–75. <http://dx.doi.org/10.1016/j.fct.2009.09.017>.
- Zanatta CF, Ugartondo V, Mitjans M, Rocha-Filho PA, Vinardell MP. 2008. Low cytotoxicity of creams and lotions formulated with Buriti oil (*Mauritia flexuosa*) assessed by the neutral red release test. *Food Chem. Toxicol.* **46**, 2776–2781. <http://dx.doi.org/10.1016/j.fct.2008.05.001>.
- Zullo BA, Ciafardini G. 2008. The olive oil oxygen radical absorbance capacity (DPPH assay) as a quality indicator. *Eur. J. Lipid Sci. Technol.* **110**, 428–434. <http://dx.doi.org/10.1002/ejlt.200700136>.